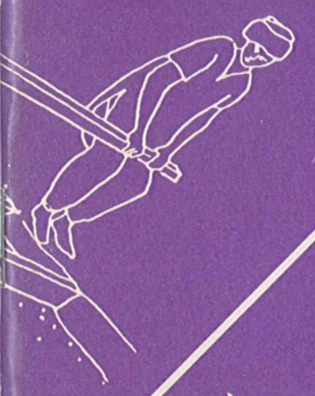
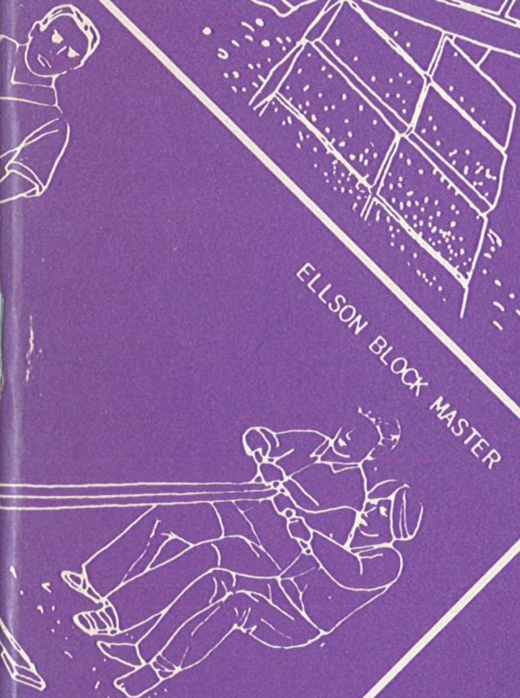
UNCHS (Habitat)

Earth Construction Technology

Manual on Production of Rammed Earth, Adobe and Compressed Soil Blocks





EARTH CONSTRUCTION TECHNOLOGY

MANUAL ON PRODUCTION OF RAMMED EARTH, ADOBE AND COMPRESSED SOIL BLOCKS

United Nations Centre for Human Settlements (Habitat)

Nairobi 1986

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FOREWORD

In most rural areas of the developing countries and in some urban low-income settlements, earth is the main material used for shelter construction. Under these circumstances, earth construction is characterized by dilapidated, temporary and unsafe structures. In fact, living examples of good, durable and attractive earth buildings are hard to come by, while the popularity of the material has dwindled to the extent that, even in circumstances where it should be the obvious choice in rural housing construction, preference has been given to relatively modern materials.

In principle, soil is not restricted to low-cost construction, but, rather, forms the basis of a technically sound engineering practice which is comparable to concrete technology or that of any of the popularly adopted building materials. Ultimately, a building material responds to clearly defined functional requirements in the construction process. The merit of earth in construction should be judged by its ability to fulfil a number of construction tasks - notably as a material for walls, floor, renderings and even for roofs. The issue of earth being a low-cost material is incidental and, indeed, an added advantage to these technically viable properties. For this reason, the material should be promoted alongside other conventional materials to the extent that professionals in the construction sector can make a choice for earth in preference over or as an alternative to comparable materials. It is along these lines that the objectives of wide-scale adoption of the material could be achieved while meeting the construction needs of the low-income population.

Following this principle, earth construction faces an obvious disadvantage in comparison with other popularly adopted materials. There is limited knowledge of good earth construction practice. The construction technologies which are predominant in the informal channels for artisan training are defective and inappropriate. In the conventional technical and professional training institutions, there is hardly any coverage of the subject of earth construction apart from basic civil engineering consideration. While architects, town planners, civil engineers, quantity surveyors and numerous sub-professionals in the construction sector have a role to play in promoting the use of earth, the foremost task is to fill a gap in their knowledge, i.e., to provide adequate technical information on earth construction for use by professionals in field implementation projects. It is for this purpose that this set of publications has been provided.

This series of publications on earth construction is made up of four technical manuals, namely, (1) Manual on basic principles of earth application, (2) Manual on production of components, (3) Manual on design and construction techniques, and (4) Manual on surface protection. The four manuals are complementary to each other, yet

each is presented in a distinct and concise manner to respond to a specific component of the subject.

These manuals are intended for professionals dealing with projects on earth construction and should serve as useful reference material and aids in actual field practice. This current publication will be supplemented by other publications on various aspects of earth construction for the benefit of a wider group of professionals, programme administrators and policy-makers who are concerned with the subject. Eventually, it is expected that all these efforts will contribute to the provision of detailed and simplified manuals for use by the ultimate field worker - the technician or the craftsman.

The preparation of these manuals is based on an extensive project on earth construction technology undertaken by UNCHS (Habitat) in collaboration with the Government of Belgium. UNCHS (Habitat) is deeply grateful to Messrs. Hugo Houben and Guillaud Hubert, who were the principal consultants for the project.

A. Ramachandran

Dr. Arcot Ramachandran
Under-Secretary-General
Executive Director

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INTRODUCTION

Present day earth construction employs production techniques ranging from the most rudimentary and artisanal to the most sophisticated, relying on industrial, mechanized and even automated processes.

Earth technology is no longer a matter of purely artisanal production or third world techniques which offer no potential for development. The passage from artisanal to industrial production, although technically possible, must obviously be justified by the parameters governing each particular case, such as development policy, socio-economic and cultural considerations, economic and technical base, investment, work procedures, etc.

For example in craft production, five people can produce from 500 adobes (in West Africa) to 2,500 adobes (in Egypt and the Islamic Republic of Iran) per day, with no investment outlay being required. In industrial production in the United States of America five workers can produce up to 20,000 adobes per day, but with an investment outlay of the order of $ 300,000. Despite the current infatuation with mechanized systems, these are frequently unable to achieve qualitative and quantitative targets. The following remark by Joe Tibbets in the American magazine Earth Builder is worth quoting, "A machine is no better than the soil you put into it". It is not the machine that guarantees the quality of production but rather how production is organized and the skill of the operators. The real return of a mechanized production process is often only a tenth of what is commercially claimed for it, and a product that looks beautiful at a demonstration may be a sorry sight after a few years. The fact that earth construction is practiced throughout the world

dictates that an in-depth study of the tools of production is undertaken at all levels of the production process right up to the building and maintenance stages. Here we will limit ourselves to the three most frequently used of the 12 techniques discussed: compressed block, rammed earth and adobe.

Whatever the production methods, manual or mechanical, the operations involved are almost identical. This is particularly true for the excavation, transport, preliminary drying, and storage of the raw material, and the crushing and screening, proportioning and mixing, and drying and storage of the end product.

I. THE PRODUCTION OF RAMMED EARTH

A. Preparation of the soil

The soil used for rammed earth construction is characterized by its variable cohesion in the natural state. Production can be facilitated or complicated depending on the cohesiveness of the material. Moreover, while adobe or compressed block technology can tolerate some variation in soil quality - which can be compensated by taking the appropriate measures in the production phase to ensure the quality of the structure - rammed earth technology is less flexible. The quality of a house built in rammed earth depends to a great extent upon the soil being of a consistently high quality. The raw material excavated from the borrow must meet this requirement for a material of a more uniform quality. In non-stabilized rammed earth construction, builders must ensure that the earth to be used satisfies the selection criteria, and this in particular with respect to its texture and moisture content. This simplifies the entire production process, though this is not the case when other stages such as screening, pulverization and dry and wet mixing are necessary, for example for cement or lime stabilization. Too wide a departure from the limiting grain size distribution curve has, among other things, a very harmful effect on the cost of production as well as on productivity and on the quality of the product.

1. Soil excavation

(a) Manual

This operation makes use of simple manual tools. These are generally the same as those used in agriculture, mining or road construction and includes picks, mattocks, spades, shovels, crowbars, rakes, etc. Manual excavation requires a great deal of manpower.

(b) Mechanical

Various mechanical devices can be used. The mechanical shovel can be variously fitted out to match the work: as a high loader, excavator, grab, or clamshell excavator. A bucket chain excavator is suitable for working an even embankment with a gentle gradient. A bulldozer with blade, an angledozer or a scraper can be used for the horizontal excavation of large volumes of earth. A power cultivator fitted out with a cutter has the advantage of combining excavating and aeration operations and, in addition, rendering the earth highly homogenous. Dual-purpose machines capable of performing the functions of both excavation and elevation significantly increase the productivity of the production process and to some extent make scaffolding unnecessary.

2. Screening

It is frequently necessary to screen the earth to be used in rammed earth construction. This can be done by removing the largest stones manually, i.e., those having a diameter greater than 50 mm. Static screens can be used with equal success. These are set up horizontally or obliquely and the mesh size should correspond to the desired grain size. As soil suitable for ramming is a powdery material, most vibrating screens are eminently suitable for processing it.

3. Pulverization

If earth is to be rammed, it must be pulverized. This also applies to excessively clayey earth containing hard lumps and to which a sandy fraction must be added. It is advisable to group the pulverizing, grating and mixing operations together. With regard to improving clayey soil with sand, processing the clayey fraction and the sandy component in the pulverizer in alternating fashion will result in a premix of reasonable quality. The mixture goes through the following sequence of further operations: transport, elevation and distribution within the formwork. The pulverizer must be a sturdy machine able to handle stony and sandy soil, and it must be able to project the earth a certain distance in order to ensure good aeration and proper premixing.

4. Mixing

Mixing is advisable when the soil requires homogenization or when it is desirable to add a stabilizer. The most suitable piece of equipment for this operation is a concrete mixer, but a motor cultivator also gives good results in most cases.

5. Transport

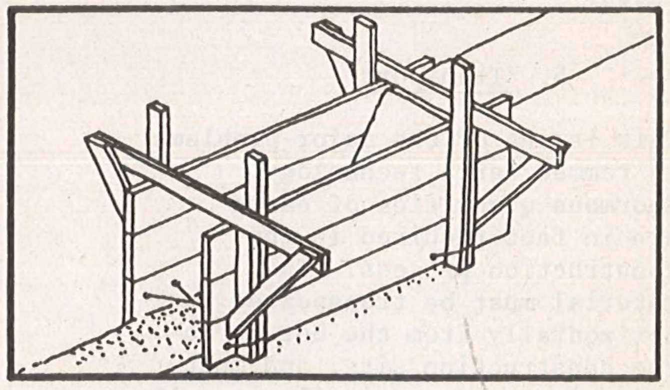
This is one of the major problems in rammed earth technology. Enormous quantities of earth are in fact required in the construction process. The material must be transported horizontally from the borrow to the construction site, and must be transported vertically as well to the required level. Traditionally, workers who built with rammed earth use manual labour to carry the soil in heavy or light baskets or other receptacles from the borrow to the construction site, the material then being raised by ladder or scaffold to where it is used. The same task can also be carried out in a highly efficient manner by means of hoists. Rendering projectors have been adapted to the same end by a complex process, since the material is not liquid. From a central position the earth can be pumped to anywhere within 40 to 50 m to a height of 100 m.

B. Formwork

1. Basic types

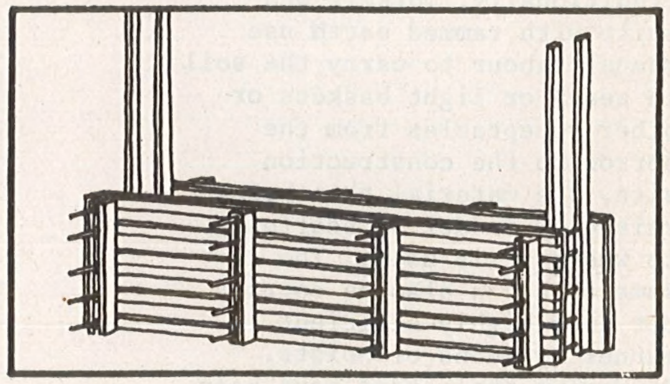
Experience shows that formwork is most effective when it is small and simply designed. It must be solid and stable in order to resist the pressure and vibrations resulting from the ramming (a minimum of 300 daN/M^2). It must be easy to manage, i.e., light and easy to assemble and dismantle - plumb, fit and fastening must be good. Lastly and most importantly, the formwork must be perfectly capable of accommodating changes in height, length and thickness of the walls. A broad range of materials can be used for the formwork such as wood in Morocco, logs in China, aluminium in France, steel in Algeria, and glass fibre.

(a) Horizontally sliding formwork



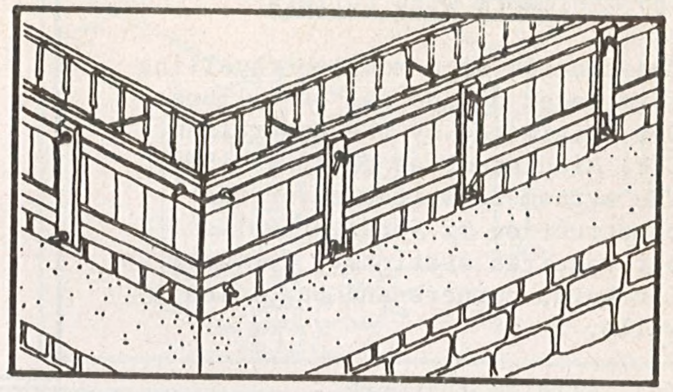
This system has been traditionally adopted for rammed earth construction. This type of form-work system was developed by craftsmen and differs widely. It uses fastening systems which follow the principles elaborated above and has the following major advantages: lightness, manoeuvrability of the equipment, adaptability.

(b) Vertically sliding formwork



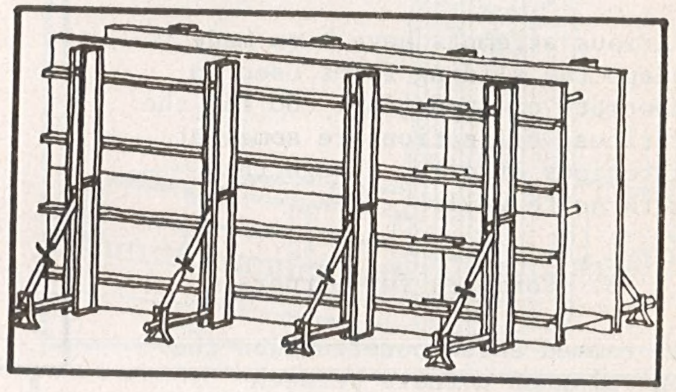
This system is ideally suited to the construction of rammed earth walls in piers. It facilitates and greatly accelerates the erection of a structure but the formwork must be carefully designed. The vertical elements holding the formwork in position can be formwork bottoms, construction posts or external frames.

(c) Integral horizontal formwork



A ring of formwork is moved vertically. Success demands that the elements be light and that assembly and disassembly be easy and rapid. The chief obstacles are the joints between the boards, horizontal alignment and the maintenance of plumb.

(d) Integral vertical formwork

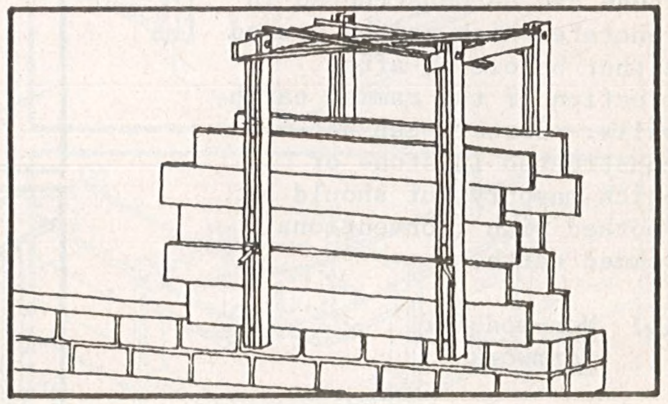


This type of formwork lends itself to the construction of large piers, contained in the formwork for their entire height. In order to facilitate ramming, only one side of the formwork is completely erected. The second is erected as the wall is constructed.

2. The movement of formwork

The moving of formwork poses a serious problem for workers when they are perched at a height of 7 m above the ground on a 40 cm thick rammed-earth wall. The safety of the worker is essential. As a general rule, the lightness and manoeuvrability helps to ensure safety. Means have been sought to avoid the total dismantling and reassembly of the formwork after moving.

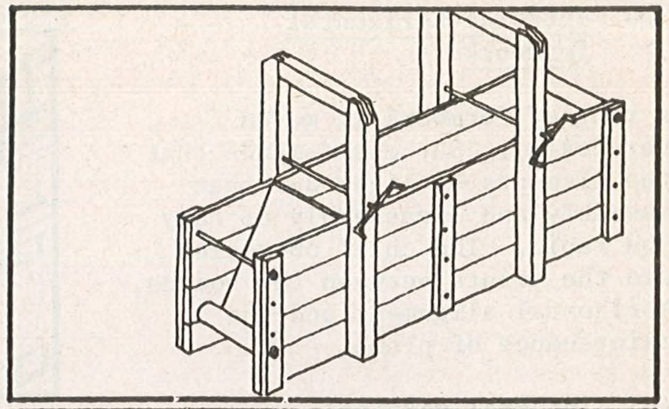
(a) Gantry formwork



This technique is best suited to the construction of piers or wall sections. The formwork is light, consisting of simple planks, plywood panels or even billets which are kept in position by wooden supports driven into the ground and secured at the top. This type of system is used in Chinese rammed earth construction. CHS in Kassel has reintroduced the technique with a system involving a wooden hinged frame, fastened by threaded rods.

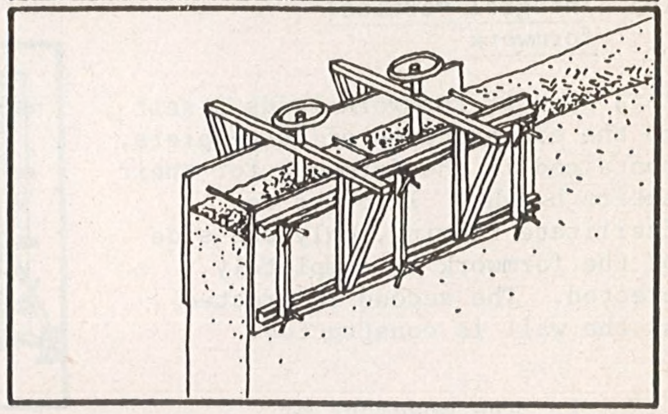
(b) Formwork with rollers

The concept of a mobile travelling form based on the use of rollers was originated by the Australian C.F. Middleton, as early as 1952. The system is suitable for the construction of straight walls but requires stationary formwork for bays, corners and partition walls.



(c) Sliding formwork

Various attempts have been made to adapt the sliding forms used in concrete construction. So far the various realizationsare somewhat laborious affairs, though they work quite well.

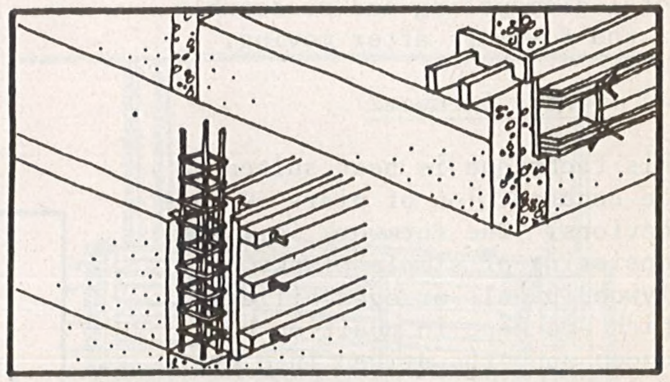


3. Formwork for corners

In rammed earth construction the building of corners between walls requires the use of special formwork. The play allowed for in the formwork for sections of perpendicular wall can prove to be inadequate if insufficient attention is paid to corners. These can be fashioned all of a piece or by the alternate, perpendicular overlapping of boards. The provision of chamfered edges reduces the erosion of outside corners. The "T-system" used for bonding partition walls assumes the same principles as those applied to the corners.

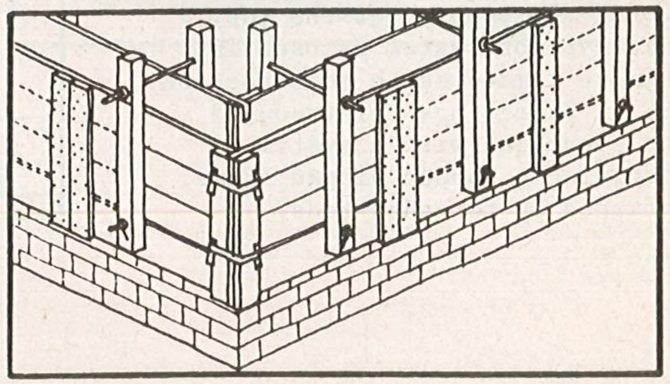
(a) Corner posts

These can be constructed in concrete which can be poured either before or after erection of the rammed earth walls. Corners can be constructed in stone or brick masonry but should be toothed with (conventional) rammed earth.



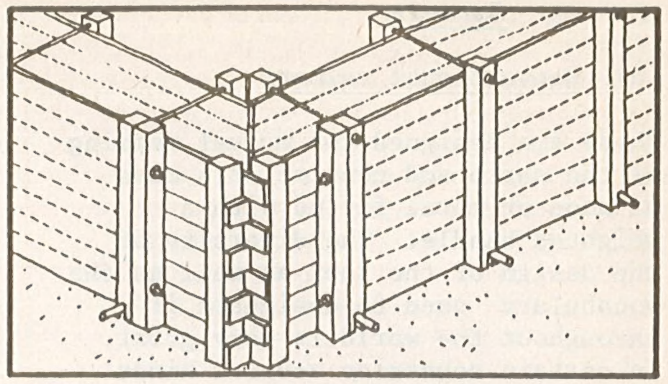
(b) Non-modular formwork

Each corner is constructed using a special element adapted to the particular conditions resulting from the use of non-modular formwork.



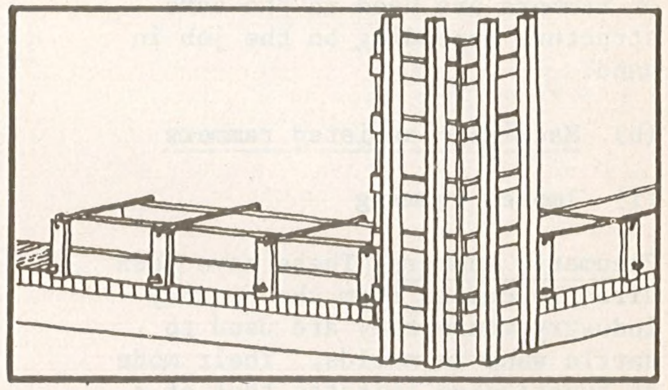
(c) Modular formwork

In this system corners are constructed as a single piece, coupling the two inner panels and using a modular formwork on the outside. The design and external dimension must be very precise.



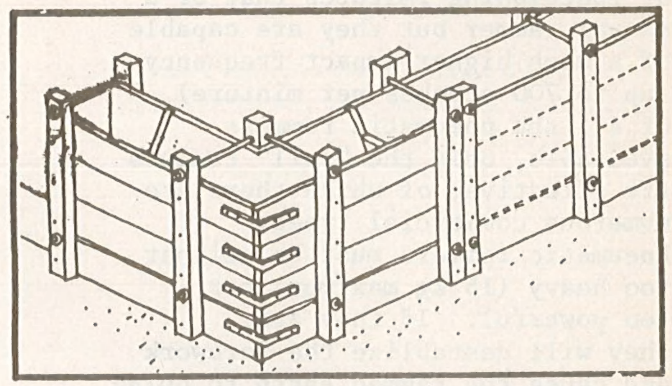
(d) Integral corner

This system can accommodate the setting up of a formwork that can form an integral corner from the bottom all the way up to the top of the building under construction. In this way it takes care of the very tedious problems of plumb and adjustment.



(e) Symmetric formwork

The formwork for both inner and outer faces is modular and symmetric. This system solves the problem of adjusting the panels, but it does not altogether eliminate the risk of a corner separation crack.

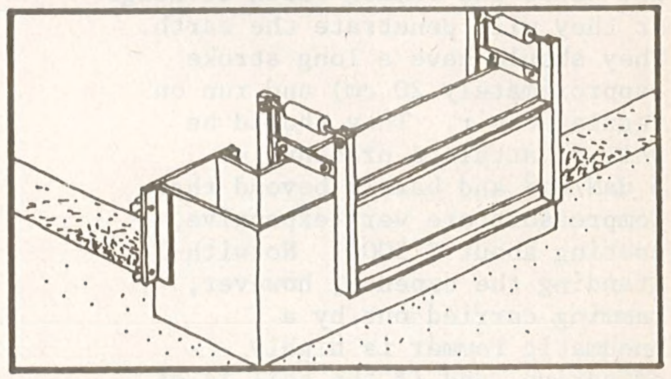


(f) A symmetric formwork

This system is sounder than the completely symmetric corner, given that the forms can be inverted thus eliminating the danger of corner separation cracking.

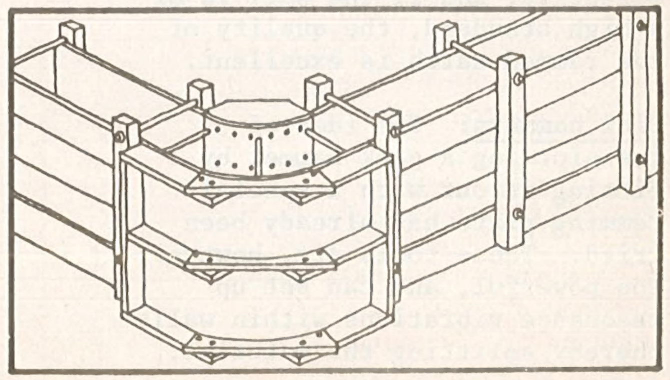
(g) Variable formwork

The angle of the corner being formed can be varied by means of systems that incorporate regular or lift-off hinges. These systems are delicate and always pose the problem of gauging the fit of the panels.



(h) Rounded formwork

This corner requires special formwork, produced on the site, which can accommodate architectural features. The corresponding operation is very delicate, costly and difficult to carry out.



4. Rammers

(a) Conventional rammers

These are designed for manual ramming of the earth and consist of a mass of wood or metal fitted with a weighted handle. The diversity of the design of the tool as well as the vocabulary used to designate it throughout the world is very great. In certain countries several kinds of rammers are used in the same structure depending on the job in hand.

(b) Machine - assisted rammers

(i) Impact ramming

Pneumatic rammers: These have been directly copied from the foundry industry where they are used to settle sand in moulds. Their mode of functioning imitates that of a manual rammer but they are capable of a much higher impact frequency (up to 700 strokes per minture). Of all the pneumatic rammers available, only the "soil" rammers are effective, of which there are numerous commercial types. Pneumatic rammers must be neither too heavy (15 kg maximum) nor too powerful. If they are, they will destablize the formwork and cause the rammed earth to bulge or they will penetrate the earth. They should have a long stroke (approximately 20 cm) and run on regulated air. They should be able to attain a pressure of 5 daN/cm^2 and barely beyond that. Compressors are very expensive, costing about \$ 5000. Notwithstanding the expense, however, ramming carried out by a pneumatic rammer is highly effective, and if the soil is of a high standard, the quality of the rammed earth is excellent.

Pick hammers: The idea of transforming a pick hammer by fitting it out with a special ramming plate has already been tried. These tools are, however, too powerful, and can set up resonance vibrations within walls thereby splitting the material.

(ii) Vibration ramming

Vibrating plates: This method was developed by CHSK in Kassel. In it, a motor with an eccentric rotating mass transmits vibrations to the plate, thus causing the machine to move. A switch enables the operator to determine the direction of this movement, and the machine then functions automatically. The ratio between the weight of the machine, the speed of operation and the vibration frequency is difficult to set.

Vibrating rammers: Versions of these machines powered by combustion engines or electric motors are available on the market. They are heavy, cumbersome and expensive. Their use has been the object of numerous tests with very modest results and builders are advised against using them.

II. PRODUCTION OF ADOBE BLOCKS

A. Preparation of the soil

Soil suited to making adobes has a rather clayey or very silty texture and is quite cohesive. This cohesiveness makes excavating the earth, whether dry or wet, a difficult task. The excavation sites are often waterlogged and muddy. The traditional method of preparing the earth is thus laborious and is done on foot. The soil must be prepared with great care in order to ensure a high standard of adobe. There are other methods of preparation, some of which are mechanized. A third category, lying between the first two, utilizes draught animals.

1. Chopping of fibres

Plant fibres, generally straw, are frequently added to the soil. The stalks are cut using sharp-edged tools. However, manual and power straw choppers, capable of cutting large quantities of straw and other fibres into length of between 1 and 30 cm, are commercially available. The normal price of such choppers starts at $ 1,000 for the manual type and $ 1,500 for motor-driven ones. Fibre choppers can also be used to prepare plant cuttings destined for a methane digester.

1. Pugging

The preparation of the earth entails a long pugging operation. In many regions, animals that go round in a circle over a specified area, perform this work by treading the earth with their hooves. Animals that can be used for this purpose include donkeys, mules, oxen, and horses.

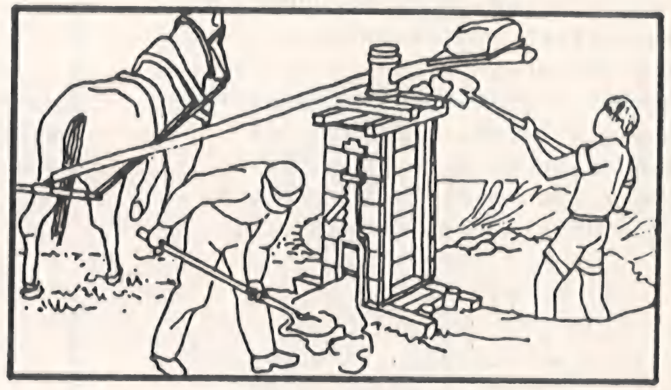
The material can be pugged in a pit with mechanized plant such as shovel excavators and tractors that can combine the operations of excavation, mixing and transport. The pit should have a stable bottom and an inclination so that the machine can get out. The

manoeuvring space for the machine must be sufficiently large. The quantities mixed are enormous, being of the order of 10 m^3/h.

Pugging can also be carried out in pug mills. These can be set up in a smallish drum and driven by a motor or else hauled by animals over a given area - two weighted truck wheels will serve the purpose. Wheel tracks should not be left in soil and this can be avoided by devising a system that throws the soil back under the wheels so that it is constantly remilled. An improvised pugging set-up costs only a few dollars while a mill in a containment vessel costs something of the order of $ 2000. Such plant is very heavy and a typical output is in the neighbourhood of 7 m^3 per day.

3. Mixing

(a) Vertical mixers

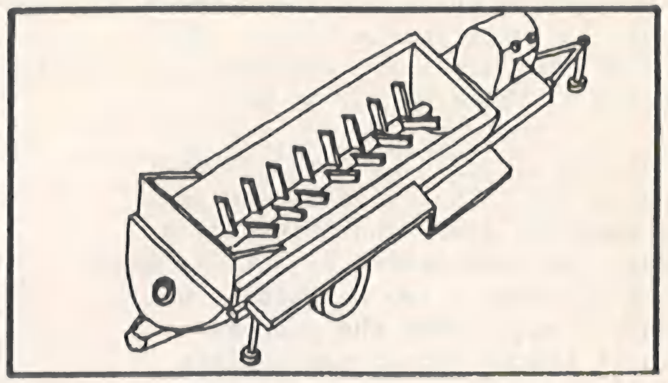


The most common can be made using very basic materials; a few planks and timbers, ropes and steel wire, etc. They can be operated by animals. The lever should be at least 2.5 m long, and the animal should not work more than five hours per day. Mechanical vertical mixers exist as well. They must be solidly built and the standard output is 10 m^3 per day.

(b) Rendering mixers

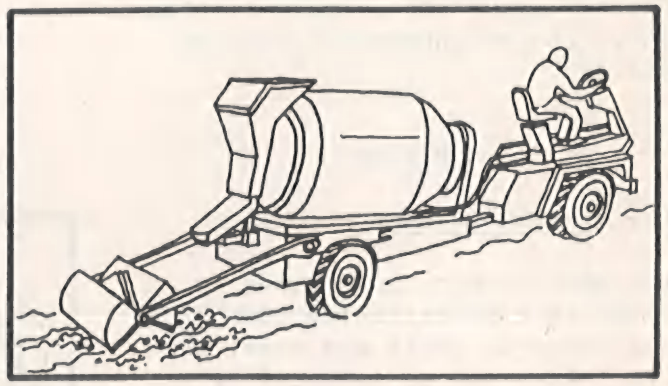
As they are very sturdy, these mixers should really be used with liquid soil rather than plastic soil. They are capable of a daily output of approximately 8 m^3.

(c) Linear mixers



These are widely used in production units capable of medium and high output. There are a number of variations on them. For example, they can have a single or double shaft; they can be of the constant or discontinuous-flow type; they can be of heavy or light construction. Their output is very high and muddy earth can be dumped into a pit allotted for the purpose. The smaller linear mixers are capable of outputs of between 4 to 5 m^3 per day. The bigger mixers, which have been adopted from the ceramics industry, have an output of 50 m^3 per day.

(d) Concrete mixers



Although poorly rated, standard tilted-drum concrete mixers are capable of doing the job. Their output is low and the resulting mixture often lacks homogeneity and suffers from lumpiness. Their main advantage is the wide range of models available, ranging from small to large, suitable for connection to a tractor PTO (power take-off), mixer trucks, and special wheeled plant.

(e) Screw mixers

It is also possible to work with small quantities using drums provided with a screw of the sort used for paint and plaster. In this way it is possible to prepare 50 litres of mixture in 10 minutes by making successive batches.

(f) Planet wheel mixers

These are ideally suited to preparing mud even when it must be mixed with plant fibres. The smallest ones have a batch capacity of 100 litres, and an output of 10 m^3 per day.

B. Manual production

1. Small-scale

Adobes can be produced with or without a mould. Very primitive production techniques are still practised. Bricks made in this way do not have a very attractive appearance nor are the walls built using them particularly solid. Prism-shaped moulds are recommended. Semi-solid, and semi-soft paste is required for manual shaping.

The paste which is put in the mould is lightly worked by hand and then immediately removed. In order for it to be removed easily, the mould must be cleaned and wetted beforehand. In this technique, called slop-moulding, the film of water that adheres to the mould facilitates release. The common type of mould has a single compartment and its dimensions are variable; it is up to 60 cm long for the heaviest adobes. It can also have multiple compartments and be capable of moulding up to four adobes at a time. These moulds are made of wood or iron, some even being made of plastic. The bricks undergo considerable shrinkage and their quality must be carefully monitored.

To proudce better quality, denser and more resistant bricks, it is advisable to work with a semi-firm paste. The mould must be very clean, and then it is dipped into water and the inside sprinkled with sand. Using this technique, known as sand-moulding, a given quantity of earth is shaped roughly into the form of a ball, rolled in the sand and then thrown with force into a single-compartment mould. The ball is made firm with the fists, care being taken not to neglect the corners. The excess is removed with a wooden guide strip. To facilitate release, only the earth coated with sand should adhere to the sides of the mould. There are many different types of moulds,

some having bottoms and some not. The adobes are turned out of the mould on to the drying area. This technique means that the earth has to be stored near the moulding area and several moulds should be available. It is advisable to work standing at a table. There are even tables with built-in moulds and ejection levels. The adobe should be carried to the drying area on a small board (the bottom of a mould). The output using the moulding technique is of the order of 500 adobes per day.

2. Large-scale

Large-scale production requires modifications to the techniques of small-scale output as indicated in the following:

(a) Multiple moulds

These can be a ladder-like array in which moulds are juxtaposed or alternatively large parallelpiped moulds can be used. In this way 10-25 adobes can be produced at once. The earth should fill the entire mould. It must therefore be more liquid, in the soft-paste state. Apart from this change in moisture content, the previous preparation remains the same. The earth is then poured into the moulds by means of a wheelbarrow, dumper, frontloader, or even straight from the mixer which, in this case, is self-propelled, towed, or mounted on a truck. The soil is then levelled with a kind of scraper so that it is evenly distributed within the mould, including the corners. Some time may be allowed to elapse before removal from the mould, but usually this is done immediately after the previous step. The whole operations then repeated without interruption. Large moulds must be cleaned properly either by allowing them to soak in water or spraying with a powerful jet of water. The cleanliness of the moulds and the moulding stage are crucial to ensuring the quality of the adobes. Owing to considerations

of weight, the moulds should be made of wood or plastic as opposed to iron. They should be easy to manipulate by no more than two persons. Wood should be treated against rot and warping. The outputs possible with this moulding technique, with a crew of five or six workers, ranges from 8,000 to 10,000 adobes per day.

(b) Sawn adobes

It is possible to make a single very large adobe (4 m^2 for example) with a mould consisting of four two-metre long planks. A soft paste is used. The resulting adobe slab is then cut into several small adobes with a taut wire saw on a wooden support or else using a plank with a studded edge. The output using this technique is similar to that of the above technique, and only a very modest investment is required, although the finish obtained is not so good. The moulding area must be absolutely flat.

C. Mechanized production

The difference between large-scale production using multiple and mechanization processes is not all that great. The basic techniques are as follows.

1. The moulding box

A metallic mould containing a large number of compartments is mounted on a frame on wheels. The mould is lifted by means of a lever arrangement after it is filled. The adobes are deposited on the ground. The wheeled mould is then pulled to the next moulding point. The moulding cart should be capable of being cleaned each time. A mobile hopper can be added and positioned above the mould for filling by a dumper. Soft paste is poured into the mould from the hopper which is drawn over the mould. The excess earth is removed with a scraper which can be fitted to the hopper. The standard output of such a system is of the order of 7,000 to 10,000 adobes per day, and it has been refined with the development of the Hans Sumpf moulding box in the United States which was designed as an independent unit. This machine can achieve an output of 20,000 adobes a day. The adobes are deposited on to impermeable paper which is unrolled directly onto the ground on a gigantic production area. The adoption of a machine of this sort means that the entire upstream produciton plant must be modified to cope with the enormous increase in capacity.

2. The cutter disc box

Cutting by means of a wire can be automated and the wire replaced with cutter discs. A hopper fitted with a barrel lays down a continuous sheet of soft paste which is cut into thin strips. The machine is stopped at a fixed distance from its starting point and the thin strips are cut transversally by another set of cutter discs. The

output is very high, amounting to 15,000 blocks a day, and the investment is low. The production surface must be very flat and clean and the mixture highly homogenous and of an ideal consistency. The user of this system must therefore be absolutely sure of what he is doing. To date only prototypes are known, but these appear to be most promising.

3. Extruders

The extrusion of adobes opens several very attractive possibilities. Applied to the manufacture of adobes, extrusion can serve as the basis of three principal processes.

Vertical extruder: This consists of a vertical mixer provided with an extrusion nozzle. The system can be motorized or it can be driven by a draught animal. The process, although giving good results, is hardly used nowadays. With a small mixer weighing about 500 kg, output can reach 1,500 bricks per day.

Horizontal extruder: Adapted from the ceramics industry, this machine was widely used in the United States in the 1940s. It is still standard in India. Although it involves a heavy financial outlay, the system is efficient. It is capable of the same production rates as achieved in the brick industry for equivalent products. Nevertheless, the soil used for making adobes is sandier than that used for making burnt bricks. Consequently it is more abrasive, and a significant degree of wear, resulting from friction must be allowed for.

Mobile extruder: Mobile extrusion units mounted on a frame on wheels are commercially available nowadays. These are heavy pieces of equipment weighing approximately 30 tons and combine a mixer, a generating unit and an extruder. Some units are already operational in various parts of the world for the production of burnt bricks. They could also be adapted to the production of sun-dried bricks. The system has an output of between 2,500 and 3,000 bricks per hour.

4. Press

The traditional moulding table can be replaced by a press. The moisture content of the soil is not the same: and soil is either a semi-solid or solid paste. The required pressure does not exceed 20 daN/cm^2. One or more holes 10 mm in diameter are bored into the cover so as to facilitate the extrusion of any excess. Sometimes a small board is inserted into the mould and the earth ejected onto this for transportation. Output is much higher than it is for compressed blocks.

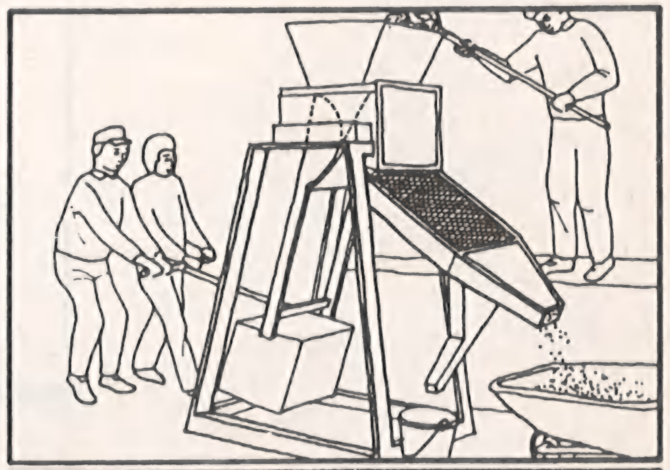
III. PRODUCTION OF COMPRESSED BLOCKS

A. Pulverization

In order to obtain uniform mixing of the mineral components, water and stabilizer, lumps of more than 200 mm in diameter after excavation must be broken up. Grains with a homogenous structure, such as gravel and stones, must be left intact, and those having a composite structure (clay binder) broken up so that at least 50 per cent of the grains are less than 5 mm in diamter. The soil must be dry. Wet soil can only be handled by certain mechanized systems. Two basic approaches are used:

(a) Grinding followed by screening. The material is pressed between two surfaces - a rather inefficient and tedious process in which useful stones are broken up. Only simple machinery is required.

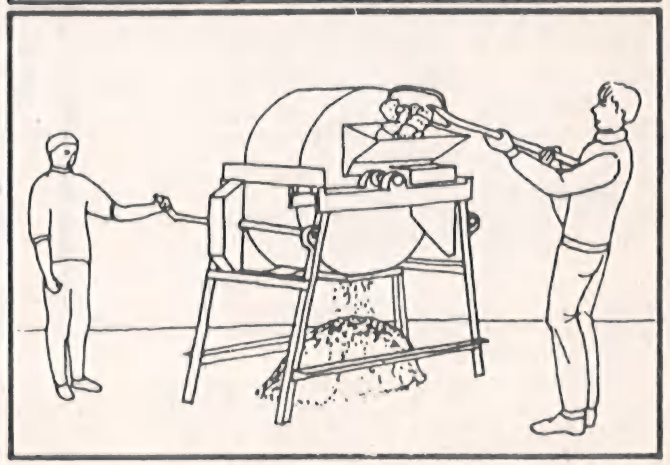
(b) Pulverization: The material is hit with great force and disintegrates. The machinery required is complex but performs satisfactorily. At the delivery end, any large pieces left can be removed by means of a screen.



The following are some of the techniques used for pulverization.

(a) Pounding: Manual process; very slow; 1 m^3 per day per man; screening absolutely essential.

(b) Jaws: Elementary mechanism - reciprocating motion; manual version. Output: 3 to 4 m^3/day. Weight: 150 kg.



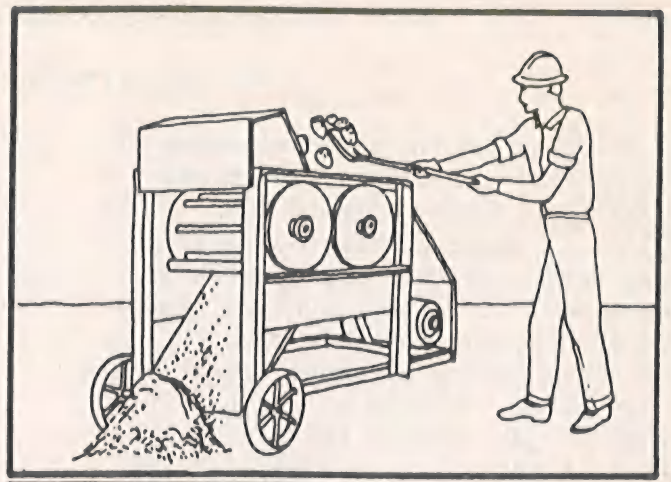
(c) Carr: Four series of rods turning at 150 rpm. Manual or motorized (electric) version, 1.5 W motor. Excellent mechanical efficiency, up to 10 m^3/day. Weight: 260 kg.

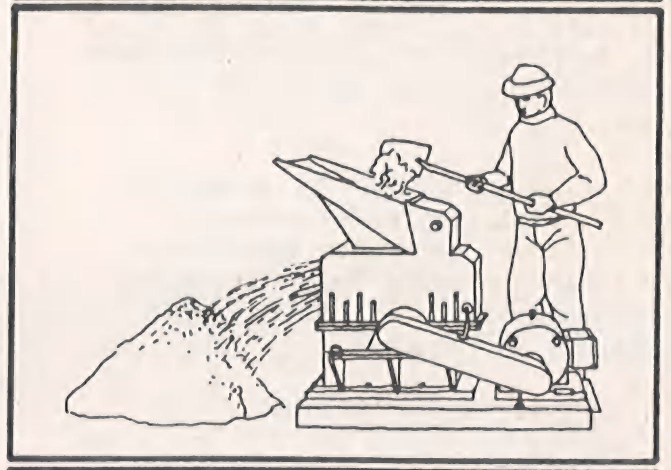
(d) Squirrel cage: Very rapid rotation: 600 rpm, 3 hp electric motor. Output: 15 to 25 m^3/day. Weight 150 kg.

(e) Hammers: Several spring-mounted hammers on a central axle beat the earth at a high frequency. 10 hp electric motor. Output: 40 m^3 per day. Weight: 200 kg.

(f) Screw: The same system as used in conventional composting machines. Indeed such machines can also be used if care is taken to avoid excess wear. Single screw or a set of screws. 5 hp diesel motor. Output: 15 m^3/day. Weight: 200 kg.

(g) Toothed belt: Only machine with a hopper - highly efficient. 3 hp motor: petrol. Output: 30 m^3 per day. Weight: 100 kg.





B. Screening and mixing

1. Screeening

This operation is absolutely essential when: (a) removal of excessively large elements or organic matter is required; (b) after the structure of the soil has been corrected by an incomplete pulverization. In most cases grains with a diameter of between 10 and 20 mm are passed - 10 mm for presses sensitive to compression and between 20 and 25 mm for those less sensitive to compression (hyper-compression). There are four basic methods of screening.

(a) Fixed screen

Set up either obliquely or suspended. The operation is manual and easy to carry out. There are two basic operations. Raw soil is thrown with a shovel against the sieve. The sieved soil is loaded into a wheelbarrow, unsieved material is rejected, or set aside from other use. Low yield: 1 m^3 per hour per worker.

(b) The alternating screen

The simplest process consists of placing a frame sieve, on a pipe and a wheelbarrow. The sieve can also be suspended from a branch and set moving back and forth. A special manual tool has been designed along these lines by the Tallahassee School of Architecture. It consists of a few planks, a cut-away barrel and chicken wire. The output obtained using the stationary sifting system is to m^3/hour per worker.

(c) Rotary screen

A cylinder made of wire netting or metal is rotated either manually or mechanically. Its construction is very simple. It is possible to pass the soil through a number of stages

series and so separate into several fractions. Agricultural rotating sieves such as peanut sieves are suitable for the operation. Mechanical rotating sieves of all sizes ranging from 1 to 30 hp are commercially available. Theoretically these sieves are capable of an output as high as 14 m^3/hour.

(d) Vibrating screen

Either a single vibrating screen or a combination of several screens, usually superimposed, can be used in this process. This system offers the same advantage as the rotating sifter in that it makes it possible to separate the soil into several fractions, permitting its reconstitution. They are used in excavations and quarries. Vibrating screens of average size have outputs in the region of 5 m^3 per hour.

2. Mixing

This is a particularly important stage. A uniform mixture is essential, regardless of whether a stabilizer is used or not. Where manual labour is relied on, the heap of soil must be turned over at least four times. When a powerful mechanical mixer is available three or four minutes in the mixer is enough. It is important to mix the material dry first. Water should be added to the soil either with a sprinkler, or a mist sprayer, or by means of pressurized steam. Mixing can be done as described below.

(a) Manual mixing

This can be done by means of shovel, hoe, rake or any other simple tool; output: 1 - 2 m^3 per day per worker.

(b) Manual mixer

Various systems have been devised which make use of a 200-litre oil barrel. The Tallahassee School of Architecture is in the forefront of the development of such systems. Their output, at 1.5 - 2.5 m^3 per day per worker, is slightly higher than that achieved using a shovel.

(c) The motorized mixer

A motor can facilitate mixing, as this is a slow operation. Conventional concrete mixers are not recommended because of the formation of lumps and crumbs in the soil.

(d) Mixer with blades

The motor cultivator is suitable for simultaneously crushing and mixing. The range of such machines available on the market is very broad with respect to size and power. Output is upwards of 4 m^3/day.

(e) The planet wheel mixer

This is the conventional mixer used for concrete extrusion. Small mixers are difficult to find. A 0.5-hp electric motor or a 0.75-hp diesel motor is required to process 10 litres of soil. A 180-litre planet wheel mixer has an output of 15 m^3 per day.

(f) The paddle mixer

This is similar to a rendering mixer but sturdier. It works well with very dry soil but can break down if the soil is wet (12 - 15 per cent moisture content). Required power for electric motors is 0.75 hp per 10 l, and for diesel engines, 1 hp per 10 l. Output for a capacity of 150 l installation is 8 to 10 m^3/day.

(g) Linear mixer

A discontinuous helical screw shaft is fitted with either single or double blades. The shaft must be very sturdy. Extremely heavy and expensive, this type of plant is rarely used.

C. Types of presses

1. Manual presses

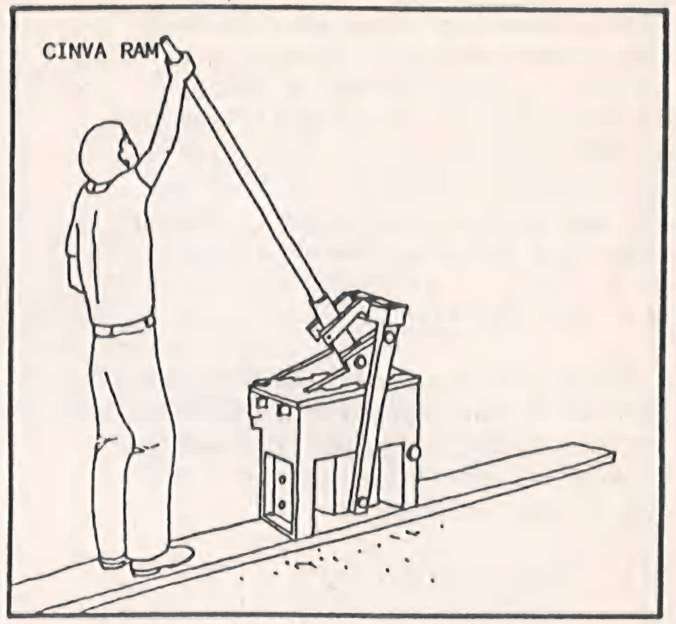
(a) Light mechanical presses

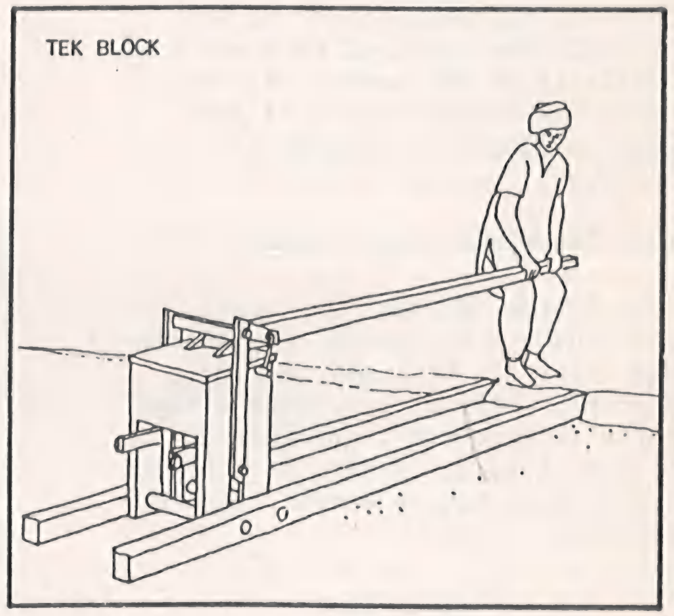
The advantages of Cinva-Ram type presses are that they are light, sturdy low cost, and simple to produce and repair. Their main disadvantages are: they wear out prematurely (coupling rings), have only a single moulding module, can exert only low pressure and have a low output. Nevertheless, they are one of the best presses of their type on the market, and it is usually the copies which wear out prematurely.

The skill that goes into the production of the Cinva-Ram is not always so well understood by its imitators. Nevertheless, this press could be improved. The following are some of the improvements designers have come up with: joining the cover to the lever (Tek-Block); better ejection (Stevin, Ceneema), greater moulding depth (Ait Ourir); better transmisssion of energy (Dart-Ram); fold-down cover (Meili); standard steel profile (Unata); dual compaction action (C + B1); compartmetalized mould (MRC1); production of perforated blocks (Ceta-ram). These technical improvements also aim at refining the production process which, in the last analysis, is relatively independent of the mechanical cycle of the press.

Production is in fact determined to a greater extent by the mode of organization of the work, the mode of payment of the crew and the prevailing working traditions. So it is that the average output of a Cinva-Ram or similar press is 300 blocks/day although this could be increased to 1,200 blocks/day.

These presses are produced in a number of countries including Belgium, Bourkina Fasso, Cameroon, Colombia, France, Morocco, New Zealand, Switzerland, United Republic of Tanzania, United States of America , Zambia, among others.





(b) Light hydraulic presses

A small press, the Brepak, makes a major improvement to the Cinva-Ram. The swivel and rod system of the Cinva is replaced with a hydraulic piston which enables it to achieve pressures of 100 daN/cm^2. The resulting blocks have identical dimensions to those made using the Cinva but are approximately 20 per cent denser. The hypercompression means that it is suitable for compacting highly expansive soils such as the black cotton soils.

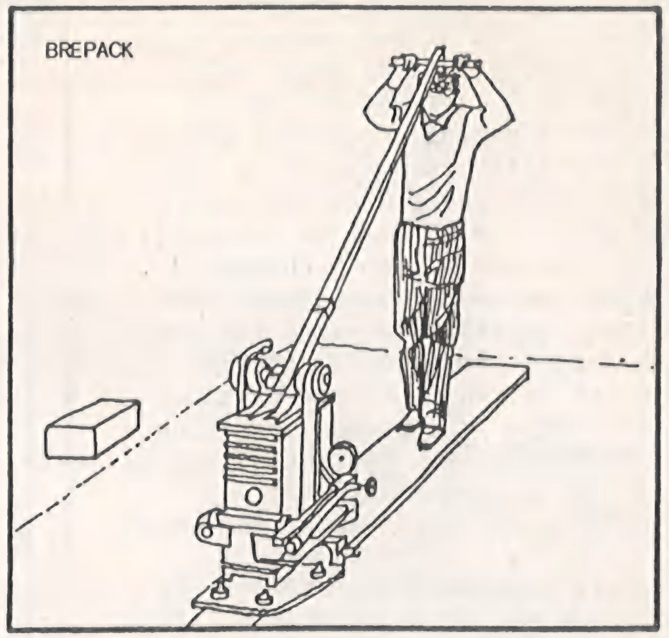
(c) Heavy mechanical presses

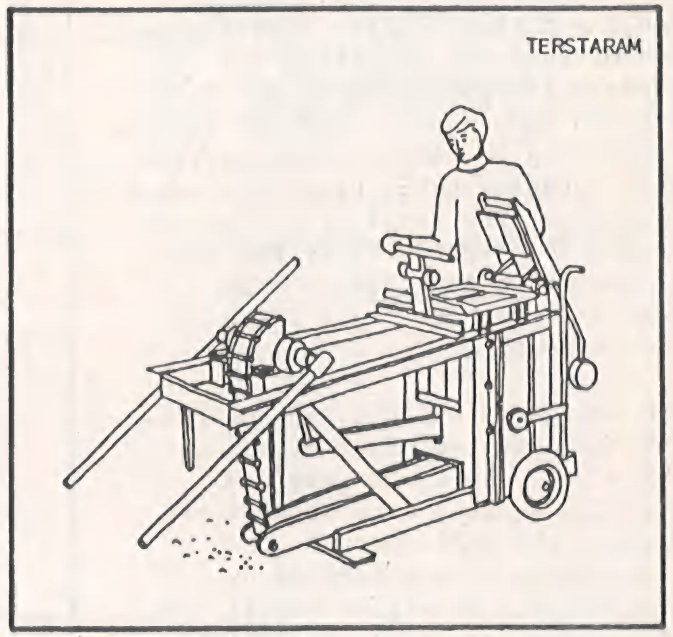
These can produce pressures greater than the minimum threshold of 20 daN/cm^2. These presses being sturdy, do not wear out easily. The presses are easy to manipulate and take care of. They have interchangeable moulds. The fold-down cover of these machines allows precompaction. The back and forth motion from one side of the press to the other is eliminated. The design of the machine permits better organization of the work that is carried out around the press.

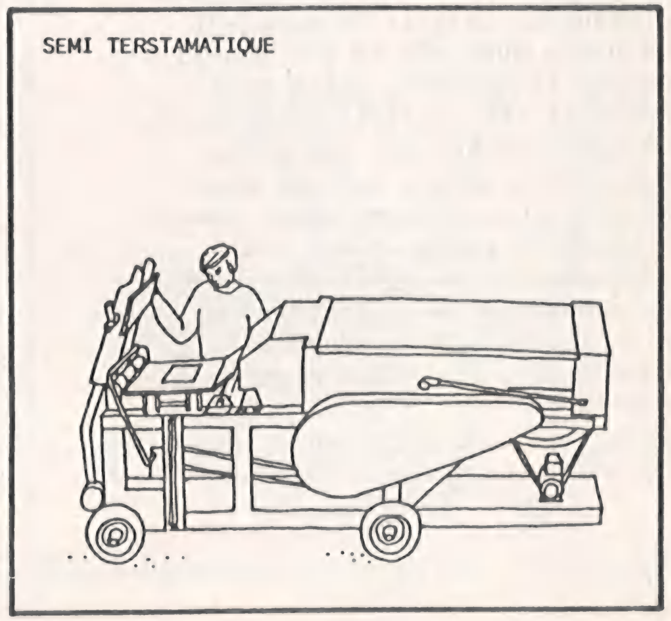
2. Motorized presses

(a) Mechanical presses

These represent a new generation of presses which are currently available on the market and which appear destined for a bright future. Despite their cost, which is of the order of four to seven times that of heavy manual presses, their economic viability is excellent. Some of these presses, such as the Semi-Terstamatic, are direct descendants of the heavy manual presses and have benefited from the lessons learned on the older type. The Semi-Terstamtic was at one time on the market under the tradenames Major and LP9 (Landcrete).





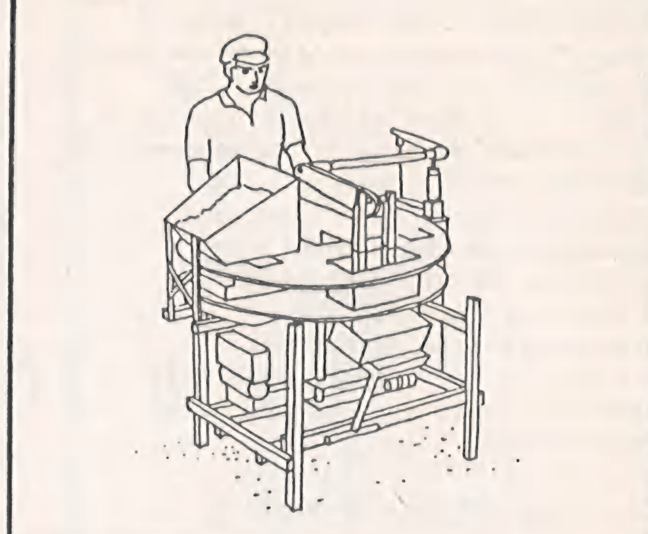


Motorized mechanical presses belong to one of two groups: those having a fixed table and single mould, simple and sturdy, and those having a rotating plate and multiple mould (three or four), which under certain conditions raises the production rate. In the first case, the mould can be changed rapidly and cheaply, whereas with a rotating plate changing the mould takes more time and is costlier. The tables can be turned by hand (Pact 500) - a tiresome operation - or mechanically. The latter system requires a more sophisticated mechanism and more energy (Ceraman).

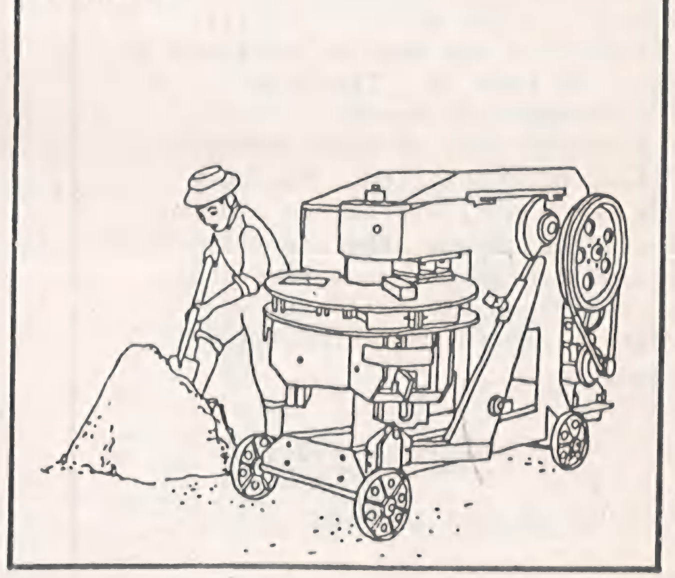
Dynamic precompaction effected by lowering the cover bocomes possible with the systems using a single mould and this confers significant advantages. By adjusting the tapered precompacting roller located between the feeding position and the compacting position, precompaction with rotating table presses becomes possible. The level of the earth should be slightly above the sides of the mould and this is only possible when the press has a feed hopper.

The designers of this type of press have encountered major problems which were still not resolved when the presses were brought to market: the soil disturbs the functioning of the machine by getting into sensitive areas; the safe operation of the machine must be assured, lest it be damaged; the press must not be allowed to operate in reverse, which would happen if the electric motor were installed backwards; where the available pressure is less than the required pressure (when there is too much earth in the mould, for example, the press will block; the removal of a half-compacted brick should slow production). Accordingly, the press ought to be provided with a compensating spring and a motor-release system.

PACT 500



CERAMATIC



Finally, these presses should be designed to give the user the choice of an electric motor, a combustion engine or another type of motor. These presses are very largely dependent on the upstream production operations of screening, proportioning and mixing.

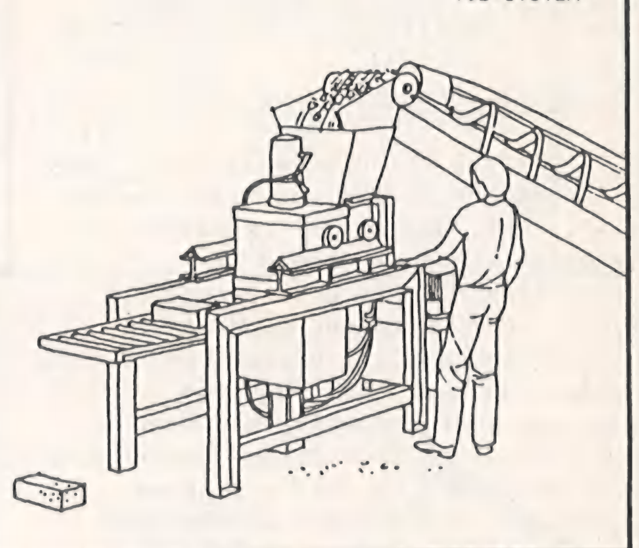
(b) Hydraulic presses

These are stand-alone presses capable of medium output. Hydraulic presses had a certain vogue in the 1950s but rapidly disappeared from the market. New presses of the same type were launched in the 1970s, but their reliability is disputed and they have brought as much disappointment as satisfaction. Nevertheless, hydraulic systems have the advantage, owing to the functioning of the piston and their compactness, of permitting a long stroke. It follows that compression ratios equal to, or greater than, 2 can be achieved.

These systems can be easily adjusted to match the composition of the soil. They can also be provided with a hopper - the first step towards automation. Furthermore double compaction can easily be carried out with a hydraulic press.

It is also true, however, that the hydraulic press gives rise to several problems all of its own, such as a delicate hydraulic pump. Apart from this if the rotating plate is hydraulically driven as well, the oil reservoir should have a volume of at least 200 l. Despite such a large quantity of oil, the temperature of the fluid can quickly rise above 70°C in tropical climates. This is the maximum permissible temperature, if all the hydraulic components are to function properly. Apart from those that can tolerate a temperature of 120°C, but which are difficult to replace if they break down, the alternative is an oil-cooling system which makes plant complex. The oil must be changed but it may not always be available.

TOB SYSTEM



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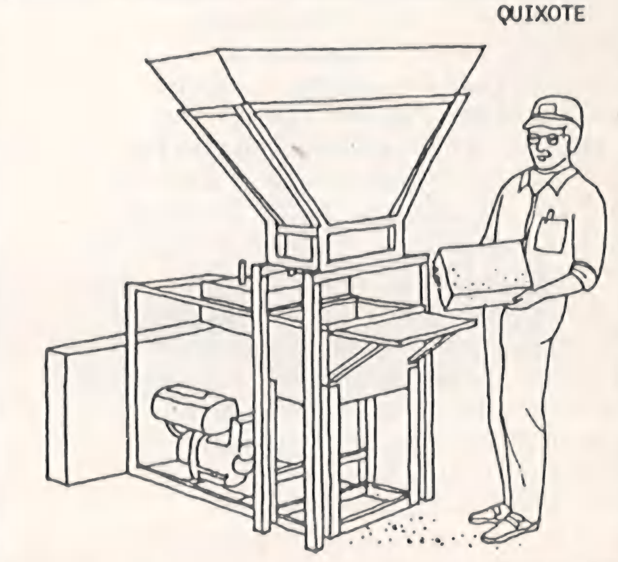


These presses may function well in the right circumstances, for example, a technologically advanced environment but they often perform poorly in rural surroundings or even on the outskirts of cities in developing countries.

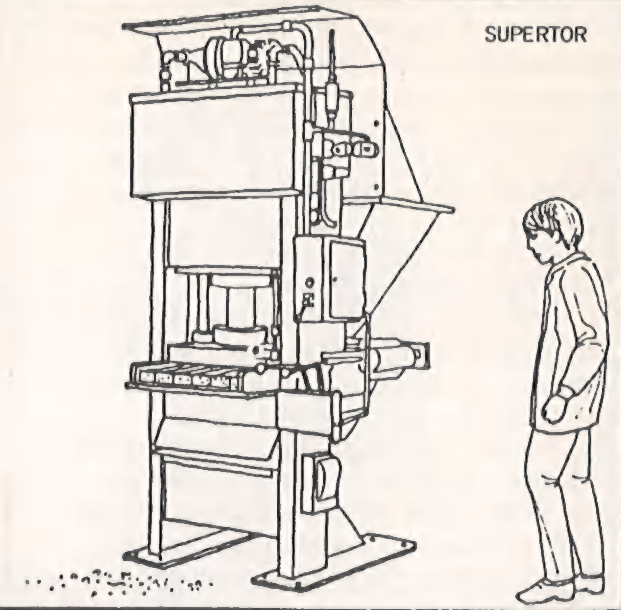
Many models of this type of press have been built and the market sees the steady appearance and disappearance of models. Rarely have they been known to be reliable.

(c) Mobile production units

Power presses often necessitate a major mechanization of the upstream process. Accordingly, designers' research has proceeded along the lines of integrating all the plant equipment used in self-contained production units, which reflect current production trends. However, although the cost can be reasonable, the economic viability of self-contained production units continues to pose a problem. They do not all operate in the same way and all conditions must be optimum. Even in the industrialized countries, these machines operate in very tight economic conditions. In developing countries they are often uneconomic. There are two types of mobile production units.

(i) Light units

These offer the advantage of opening up a totally new market in industrialized countries and in the urban areas of developing countries, namely leasing to do-it-yourself builders. Indeed these machines can be rented for the entire block production period at a relatively low price. Even so this type of machine still suffers from a few defects, mainly because of a lack of integration between the different types of equipment that have been brought together. An effort should be made to harmonize the outputs and cost of these machines to the different stages of production they integrate.


SUPERTOR

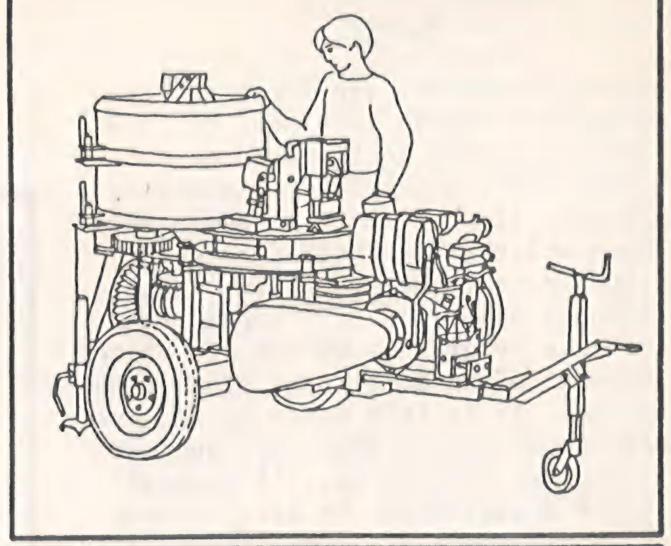
The light units can operate in mechanical presses. At present the Meili unit, which is manufactured in Switzerland, is the only example on the market of this type of press. There is not a very wide range of this class of unit and so far there is no totally integrated unit on the market. The pulverizer still suffer from defects.

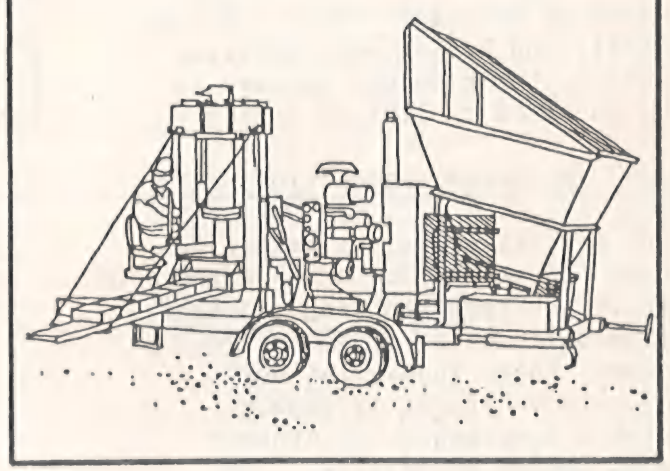
Light units are also capable of operating on hydraulic presses. The Earth Ram, the Clu 2000 and Clu 300 are only a few of the many examples of this type of unit. These machines are sometimes adapted from standing units. The principle of the design is attractive, but calculations of the cost shows that on large construction sites, it is more economic to purchase the production materials (pulverizer, mixer, press) separately. Unintegrated plant is not less efficient and it is not clear that integrated equipment is more convenient.

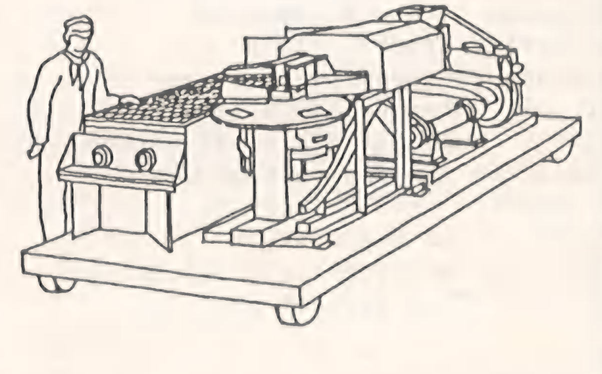
(ii) Heavy units

Some of the larger manufacturers have proposed entirely mobile units which can be taken anywhere, but which are very large and heavy. The corresponding annual production capacities are very high. The plant corresponds broadly to those described in the previous paragraph. At present there is a tendency towards the use of hypercompression. Only a few units of this type have been manufactured to date. The economic feasibility of these presses has yet to be demonstrated, and a thorough survey of the market should be undertaken before acquiring them.

At present only a single unit operating on mechanical presses is known. Its design is based on the concept of a combination of existing units all mounted on a single chassis and goes by the name of "Unipress". This plant is ordinarily used for the production of burnt bricks. Attempts in Egypt to adapt it

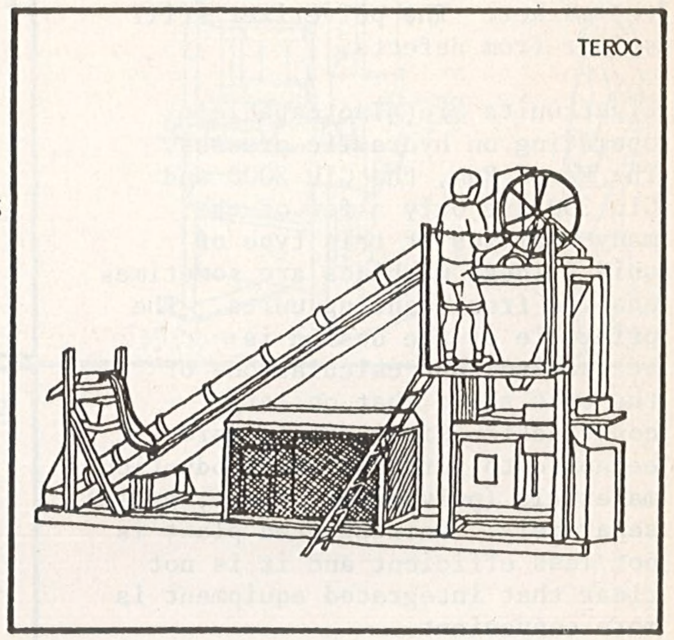
MEILI


EARTH RAM



UNIPRESS

to compressed blocks have met with some major but not at all insurmountable obstacles. The plant is very sturdy.

Hydraulic presses are presented as being all-purpose machines, but the models actually to be found on the market have, all things considered, a fairly limited range of application. These units are not equipped with pulverizers or screens. The earth, which is deposited in a hoper, is premixed by gravity with a stabilizer by means of an integrated proportioning system. It is then moved by conveyor belt to the mixer where dry and wet mixing are carried out. A storage hopper distributes the earth within the mould where it is hypercompressed and then automatically ejected in the form of blocks. These units dispose of a system of slide moulds which cannot be used to produce holow or cellular blocks. Being costly and having only moderate output, their future appears to be confined to limited markets.



(d) Industrial production units

For several years the market has seen the arrival of a whole range of fully equipped standing industrial prodcution units of a limited size. These industrial units operate on single or double static compression or dynamic compression principles. The list of products that can be manufactured by them is not limited to the small blocks which almost all the other presses can turn out. The list thus includes all the forms of concrete blocks and burned bricks which can also be made using stabilized earth, including hollow blocks and perforated bricks. This manufacturing equipment is as yet only intended for a limited market. Only massive construction programmes can ensure that the investments involved can be recovered and the cost of producing the blocks significantly reduced. This type of press is

currently used in countries such as Algeria, Brazil, Gabon, Mexico and Nigeria. There are two types of industrial prduction units.

(i) Hydraulic presses

Wholly automatic hydraulic industrial units come in several sizes. At the small end of the range, units such as the Ceramaster are fairly compact. This type is still in the prototype stage. Units of average size like the Luxor, formerly the Tecmor have been reconditioned and can handle production technology with ease. They use double compaction. Finally, the heaviest hydraulic industrial presses are veritable turnkey plants and are available in several sizes. Today it appears that only a few operational plants exist in all the world. Considerable secrecy surrounds the operation of these industrial units. The Latorex and Krupp type units make use of a stabilization process based respectively on hydrated lime and quicklime. In both cases the technology has much in common with that of the silica-limestone industry from which it has been adapted. The pressures applied are in the hyperpressure and megapressure ranges. The blocks are dried in an autoclave and operation is entirely automatic. In Nigeria and the Philippines, major problems have been encountered with this type of heavy hydraulic industrial plant. The technology that has been developed is very sophisticated indeed, and requires faultless technical control and supervision of the organization of the work.

(ii) Combined hydraulic and mechanical presses

These are equivalent to a totally automated factory. A prototype of one is currently operational in France, in the construction of the experimental "Village Terre" on l'Isle d'Abeau near Lyon. These presses have been adapted from concrete block presses. The process combines mechanical vibration and hydraulic copaction technology. By this is meant vibration at a high frequency, low amplitude (1.5 - 2 mm) and hydraulic compression at low pressure (20daN/cm^2). The frequency of vibration and the pressure of compaction can be regulated to match the soil. The production cycle consists of the following operations: filling the mould from a drawer, vibration, lowering of the plunger, raising the mould, removal of the material from the mould with withdrawal of the plunger, removal of the fresh product on a conveyor. The duration of the entire cycle is of the order of 40 seconds. This type of press can turn out solid and hollow blocks (20 x 20 x 40 or 50) at the rate of 1000 - 1500 per day or 2000 - 2500 solid blocks per day. This represents a decrease of approximately 50 per cent with respect to concrete blocks. The smooth operation of these presses requires, moreover, an adequate technological environment and well-trained and experienced operators and maintenance personnel. A tendency towards a reduction in size is currently under way. One example of this trend includes the French Dynater machine, currently under trial.

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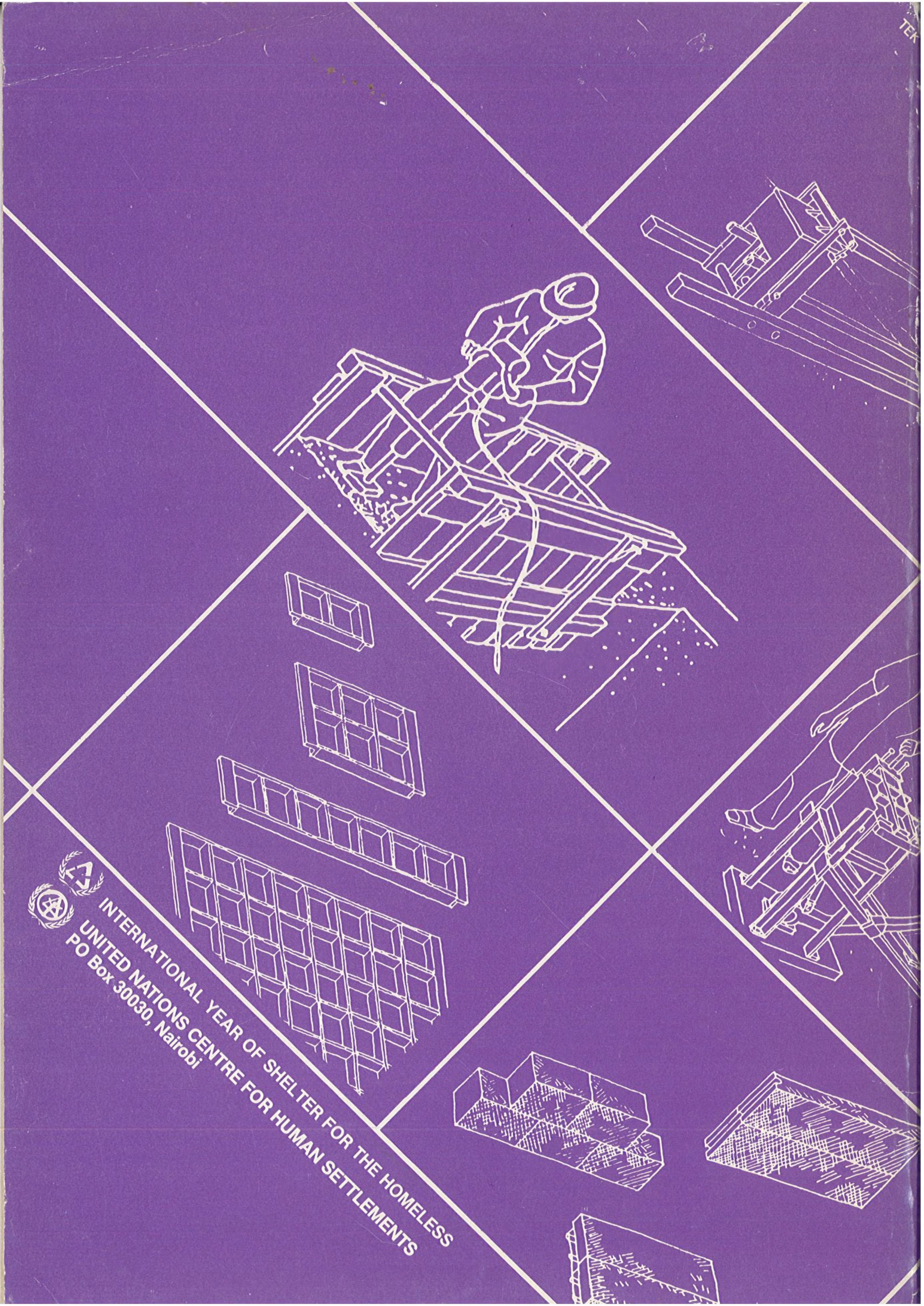

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